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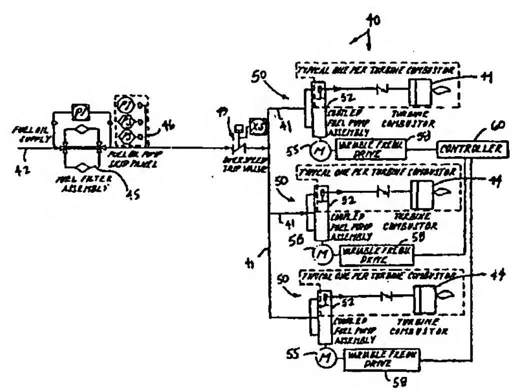

(57) Abstract: A liquid fuel system (40) is provided for controlling gas turbines. The fuel system (40) preferably includes a variable speed, coupled-element fuel pumping CEFP assembly (52) positioned in fluid communication with a fuel supply and at least one turbine combustor (44) to provide a variable supply of fuel to the at least one turbine combustor (44). The variable speed fuel pumping assembly (52) preferably includes at least one coupled-element fuel pump assembly and a variable speed drive assembly connected to the at least one CEFP assembly. The system (40) also has a variable speed fuel pumping controller (60) connected to the variable speed drive assembly to control the speed and timing of the variable speed, coupled-element fuel pumping assembly (52) to thereby control the at least one turbine combustor (44) and at least one gas turbine associated therewith. A method of controlling fuel fluid flow to a gas turbine combustor (44) positioned to combust fuel for a gas turbine is also provided. The method preferably includes supplying fuel to at least one turbine combustor (44) so that no return fuel flow path is provided and controlling the pumping speed and timing of the supplying of fuel to the at least one turbine combustor (44) to thereby enhance operating efficiency of at least one gas turbine associated with the at least one gas turbine combustor.

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SYSTEM AND METHODS FOR CONTROL OF GAS TURBINE UTILIZING VARIABLE SPEED, COUPLED-ELEMENT LIQUID FUEL PUMPS

Field of The Invention

This invention is related to the power generation industry and, more particularly, to the field of gas turbines.

Background of the Invention

In the power generation industry, the speed and power output of a gas turbine can generally be controlled by the fuel flow to the turbine combustor(s) and combustion stages. Liquid fuel supply flow and pressure are conventionally controlled by throttling the liquid fuel flow to the combustion stage(s) by the remote positioning of throttle valves and a return flow control valve. Even flow distribution to each of the gas turbine combustors is attempted to be accomplished by utilization of coupled, positive displacement, passive pumping elements commonly known as a flow divider.

FIG. 1 illustrates a prior art fuel system **10** which controls the supply of fuel to turbine combustors **14** having a flow divider assembly **25** as understood by those skilled in the art. This prior art system has a fuel oil supply line **12** which allows fuel oil to flow through or be in fluid communication with a fuel filter assembly **15** having a pressure indicator (PI) associated therewith, a fuel oil pump skid instrument panel **16** having pressure indicators (PI) and pressure switches (PS) associated therewith, a main fuel pump **17** including motor (M) and a plurality of temperature elements (TE), a main pump low-flow bypass branch **18**, an overspeed trip valve **19** having a position switch (XS), and then branched to one or more combustion stages including turbine combustors **14** and associated equipment. Each of these branches **11**, e.g., three shown, has a throttle valve **22** which includes a position transmitter (ZT), a solenoid valve (FY), a servo

valve (FC) as part of an electro-hydraulic (E/H or EH) acuator assembly, and a flow divider assembly **25** positioned in fluid communication therewith. The flow divider assembly **25**, in turn, meters an even fuel flow to each of the turbine combustors **14**. A fuel oil return line **32** is also connected to or in fluid communication with the fuel oil supply line **12**. The fuel oil return line **32** is also connected to or in fluid communication with the fuel oil pump skid instrument panel **16** and has a pump discharge pressure control valve/return flow control valve **35** having a solenoid valve (FY), a servo valve (PC), and a position transmitter (ZT) as part of an electro-hydraulic (EH) acuator assembly positioned in fluid communication therewith. The return fuel oil return line **32** then continues so as to supply the excess fuel flow back to a fuel oil tank or other fuel storage region.

This prior art fuel system **10** utilizes the flow divider assembly **25** to assure the delivery of equal fuel flow to each turbine combustor. A flow divider assembly **25** is a series of coupled, positive displacement devices whose rotation is caused by the liquid fuel passing through them. The term "positive displacement" implies that the flow divider assembly **25** passes a set amount of fluid per revolution under certain conditions. Because these elements are mechanically coupled together, each rotates at the same speed. This assures that equal flows are distributed to each turbine combustor **14**. FIG. 1 schematically illustrates a single pumping element in a flow divider assembly **25** that is ultimately tubed to or in direct fluid communication with a single combustor **14**. A single turbine would use a plurality of or numerous combustors **14** as illustrated.

These conventional gas turbine control designs such as shown in FIG. 1, however, do not have as high hydraulic efficiency as desired because of pressure losses from flow dividers, throttle valves and those portions of the system **10**

associated with the fuel return, specifically the mechanical energy required to pump and control fuel that is not utilized for combustion. These losses associated with throttling, metering, and return of excess fuel to storage greatly decrease the hydraulic efficiency of the liquid fuel system.

Summary of the Invention

In view of the foregoing, the present invention provides a system and methods for controlling one or more gas turbines which substantially increase liquid fuel system hydraulic efficiency. The present invention also advantageously provides a system and methods for controlling gas turbines which substantially lowers power generation plant electrical auxiliary loads. This, in turn, substantially increases the plant electrical output and reduces heat rate. The present invention additionally provides a system and method for controlling gas turbines which eliminates the need for many of the control and metering devices, e.g., main supply pump, throttle valves, return flow control valves, return flow piping, and flow dividers resulting in lower turbine operating and capital costs. The present invention further advantageously provides a system and method which achieves substantially more even metering of fuel to turbine conbustors as evidenced by decreased flow variation between turbine combustors. Additionally, flow measurement is enhanced over the range of fuel flow rates.

More particularly, the present invention provides a fuel system for controlling gas turbines which has at least one gas turbine, at least one turbine combustor, and preferably a plurality of turbine combustors, for maintaining combustion to the at least one gas turbine, a fuel supply positioned in fluid communication with the at least one turbine combustor, and variable speed fuel pumping means positioned in fluid communication with the fuel supply and the at least one turbine combustor for providing a controlled and variable fuel

supply to the at least one turbine combustor. The variable speed fuel pumping means preferably includes a coupled-element fuel pump ("CEFP") assembly, a motor, and a variable frequency drive which powers the assembly. The system also preferably includes controlling means connected to the variable speed fuel pumping means for controlling the speed and timing of the variable speed fuel pumping means to thereby control the at least one turbine combustor and the at least one gas turbine, i.e., the fuel flow is controlled by controlling the speed of the motor and/or the variable frequency drive.

Also, the present invention provides a method of controlling fuel fluid flow to a gas turbine combustor positioned to combust fuel for a gas turbine. The method preferably includes supplying fuel to at least one turbine combustor so that no return fuel flow path is required and controlling the pumping speed and timing of the supplying of fuel to the at least one turbine combustor to thereby enhance operating efficiency of at least one gas turbine associated with the at least one gas turbine combustor.

Brief Description of the Drawings

Some of the features, advantages, and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a fuel supply system for a gas turbine according to the prior art; and

FIG. 2 is a fuel supply system for controlling one or more gas turbines by use of a variable speed, coupled-element liquid fuel pump assembly according to the present invention.

Detailed Description of Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This

invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these illustrated embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime and double prime notation, if used, indicate similar elements in alternative embodiments.

FIG. 2 illustrates a fuel system **40** having an apparatus for controlling one or more gas turbines by the use of variable speed, coupled liquid fuel pumps. The fuel system **40** for controlling gas turbines as shown in FIG. 2 advantageously eliminates the need for many of the control and metering devices, e.g., main supply pump, throttle valves, return flow control valve, return flow piping, and flow dividers (such as shown in FIG. 1) resulting in lower fuel turbine operating and capital costs. Instead, the fuel system **40** preferably has a fuel oil supply having a fuel supply line **42** connected thereto and positioned to supply fuel oil to one or more turbine combustors **44**. The fuel oil supply line **42** allows fuel oil to flow therethrough or is in fluid communication with a fuel filter assembly **45**, a fuel oil pump skid instrument panel **46**, an overspeed trip valve **49**, and then branched to the one or more gas turbine combustion stages including turbine combustors **44**.

Each of the branches **41** of the fuel oil supply line **42** preferably has variable speed fuel pumping means **50**, e.g., preferably provided by a variable speed, coupled-element fuel pump ("CEFP") assembly **52**, which controls fuel oil to flow to the turbine combustor(s) **44**. Each of the variable speed, coupled-element fuel pump assemblies **52** preferably includes at least one pump element that is directly coupled to any additional pump elements, and a variable speed assembly motor

55 connected to the assembly **52**. The CEFP assembly **52** creates the pressure required for the combustor **44** and the motor **55** creates the necessary or required torque. The CEFP assembly **52** is a series of positive displacement pumping elements that are mechanically linked together. The assembly motor **55** delivers the power required to supply the liquid fuel at the system pressure. This eliminates the need for a main fuel pump. Each element of the CEFP assembly **52** is preferably of identical design and construction. The mechanical linkage between each element assures that the elements are rotating at the same speed or revolutions per minute ("rpm"), thus supplying equal flow to each of the turbine combustors **44**. This also eliminates the need for additional metering devices such as flow dividers. The nature of the positive displacement pumping elements eliminates the need for any pressure control as the pumps deliver fuel at the downstream conditions. This is a function of the fluid dynamics of the system **40** so no pressure control is needed.

Flow to the turbine combustor stage(s) is directly controlled by varying the motor speed of the assembly **52**. In other words, there should be a substantially linear correlation between speed and fuel flow. This eliminates the need for throttle valves. The variable speed, coupled-element fuel pump assemblies **52** provide enhanced control of the fuel flow to the turbine combustor(s) **44**. The variable speed motor **55** is preferably driven by a variable frequency drive **58** which, in turn is connected to a fuel system controller **60**. The fuel system controller **60**, as understood by those skilled in the art, can be one or more computers or processing circuits which allow synchronization, speed, scheduled timing, and other controlling features to be achieved. This variable speed, coupled-element fuel pump assembly **52** provides effective control of the flow so that only a proper and equal amount of fuel is used to control, maintain, or perform a task.

FIG. 2 also illustrates a method of controlling fuel fluid flow to a gas turbine combustor **44** positioned to combust fuel for a gas turbine. The method preferably includes supplying fuel to at least one turbine combustor **44** so that no return fuel flow path is required and controlling the pumping speed and timing of the supplying of fuel to the at least one turbine combustor **44** to thereby enhance operating efficiency of at least one gas turbine associated with the at least one gas turbine combustor **44**.

The method can also advantageously include providing a plurality of turbine combustors **44** associated with at least one gas turbine and synchronizing the fuel supplied to the plurality of turbine combustors **44** to enhance timing combustion of the at least one gas turbine associated therewith. The method can additionally include stopping the supply of fuel to the plurality of turbine combustors **44** during preselected conditions. The steps of supplying fuel and controlling the fuel are preferably provided by the use of a fuel system **40** which is devoid of at least a return fuel flow path which allows fuel to return to a fuel supply. The fuel system **40** is further preferably devoid of a main supply pump, throttle valves, a return flow control valve, and flow dividers. The method can further include maintaining combustion of each of the plurality of combustors **44** responsive to the fuel being supplied thereto.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

THAT WHICH IS CLAIMED:

1. A fuel system for controlling gas turbines comprising:

at least one gas turbine;

at least one turbine combustor for initiating combustion to the at least one gas turbine;

a fuel supply positioned in fluid communication with the at least one turbine combustor;

variable speed fuel pumping means positioned in fluid communication with the fuel supply and the at least one turbine combustor for providing a variable flow fuel supply to the at least one turbine combustor, the variable speed fuel pumping means including a coupled-element fuel pump assembly and a variable speed drive assembly connected to the coupled-element fuel pump assembly; and

controlling means connected to the variable speed fuel pumping means for controlling the speed and timing of the variable speed fuel pumping means to thereby control the at least one turbine combustor and the at least one gas turbine.

2. A fuel system as defined in Claim 1, wherein the at least one gas turbine combustor comprises a plurality of gas turbine combustors, and wherein said controlling means includes synchronizing means for synchronizing the fuel supplied to the plurality of gas turbine combustors to enhance fuel flow timing to the plurality of gas turbine combustors of the at least one gas turbine.

3. A fuel system as defined in Claim 2, further comprising at least one trip valve or at least one isolation valve positioned in fluid communication with the fuel filter assembly and the variable speed fuel pumping means for providing a stop to the fuel being supplied to the variable speed fuel pumping means during preselected conditions.

4. A fuel system as defined in Claim 3, further comprising a fuel pump skid instrument panel positioned in fluid communication with the trip valve and the fuel filter assembly.

5. A fuel system as defined in Claim 1, wherein the fuel system is devoid of at least a return fuel flow path which allows fuel to return to the fuel supply.

6. A fuel system as defined in Claim 5, wherein the fuel system is further devoid of a main supply pump, a throttle valve, a return flow control valve, and a flow divider.

7. A fuel system as defined in Claim 1, further comprising a fuel filter assembly positioned in fluid communication with the fuel supply and the variable speed fuel pumping means for filtering fuel supplied to the at least one gas combustor from the fuel supply.

8. A fuel system for controlling gas turbines comprising:

a variable speed fuel pumping assembly positioned in fluid communication with a fuel supply and at least one turbine combustor to provide a variable controlled flow of fuel to the at least one turbine combustor, the variable speed assembly including at least one coupled-element fuel pump assembly and a variable speed drive assembly connected to the at least one coupled element fuel pump assembly; and

a variable speed fuel pumping controller connected to the variable speed drive assembly to control the speed and timing of the variable speed fuel pumping assembly to

thereby control the at least one turbine combustor and at least one gas turbine associated therewith.

9. A fuel system as defined in Claim 8, further comprising a fuel filter assembly positioned in fluid

communication with the variable speed fuel pumping assembly for filtering fuel supplied to the at least one gas combustor from a fuel supply.

10. A fuel system as defined in Claim 9, further comprising at least one trip valve or at least one isolation valve positioned in fluid communication with the fuel filter assembly and the variable speed fuel pumping assembly for providing a stop to the fuel being supplied to the variable speed fuel pumping assembly during preselected conditions.

11. A fuel system as defined in Claim 10, further comprising a fuel pump skid instrument panel positioned in fluid communication with various portions of the fuel system, the trip valve, and the fuel filter assembly.

12. A fuel system as defined in Claim 11, wherein the fuel system is devoid of at least a return fuel flow path which allows fuel to return to the fuel supply.

13. A fuel system as defined in Claim 12, wherein the fuel system is further devoid of a main supply pump, a throttle valve, a return flow control valve, and a flow divider.

14. A fuel system as defined in Claim 13, wherein said controller includes synchronizing means for synchronizing the fuel supplied to a plurality of turbine combustors to enhance fuel flow timing to the plurality of gas turbine combustors associated with the at least one gas turbine.

15. A method of controlling fuel fluid flow to a combustor positioned to combust fuel for a gas turbine, the method comprising:

supplying fuel to at least one turbine combustor so that no return fuel flow path is provided; and

controlling the pumping speed and timing of the supplying of fuel to the at least one turbine combustor to thereby enhance operating efficiency of at least one gas turbine associated with the at least one gas turbine combustor.

16. A method as defined in Claim 15, further comprising providing a plurality of turbine combustors associated with at least one gas turbine and synchronizing the fuel supplied to the plurality of turbine combustors to enhance timing combustion of the at least one gas turbine associated therewith.

17. A method as defined in Claim 16, further comprising stopping the supply of fuel to the plurality of turbine combustors during preselected conditions.

18. A method as defined in Claim 17, wherein steps of supplying fuel and controlling the fuel are provided by the use of a fuel system which is devoid of at least a return fuel flow path which allows fuel to return to a fuel supply.

19. A method as defined in Claim 18, wherein the fuel system is further devoid of a main supply pump, a throttle valve, a return flow control valve, and a flow divider.

20. A method as defined in Claim 19, further comprising maintaining combustion of each of the plurality of fuel turbine combustors responsive to the fuel being supplied thereto.

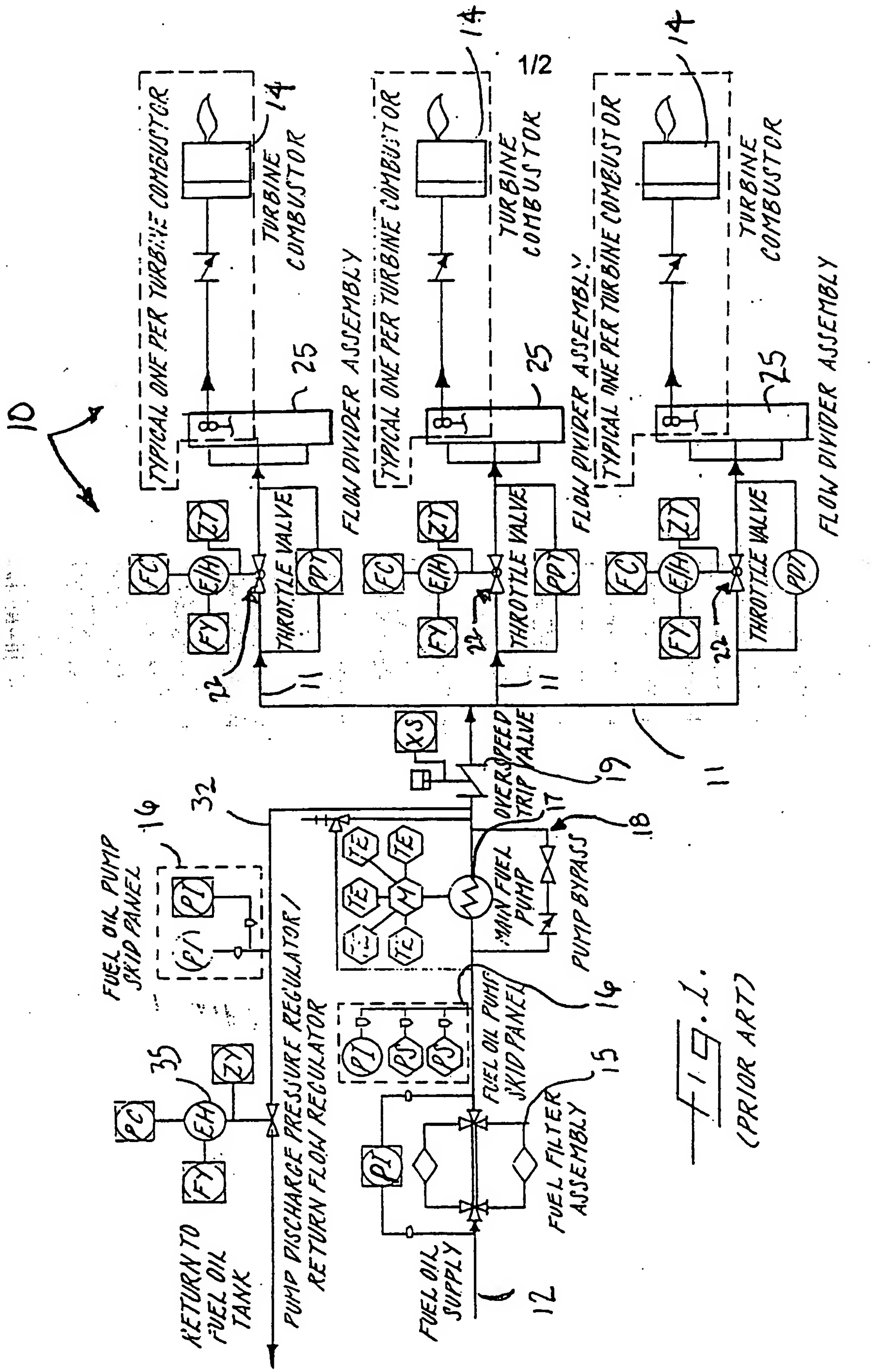

Fig. 1.
(PRIOR ART)

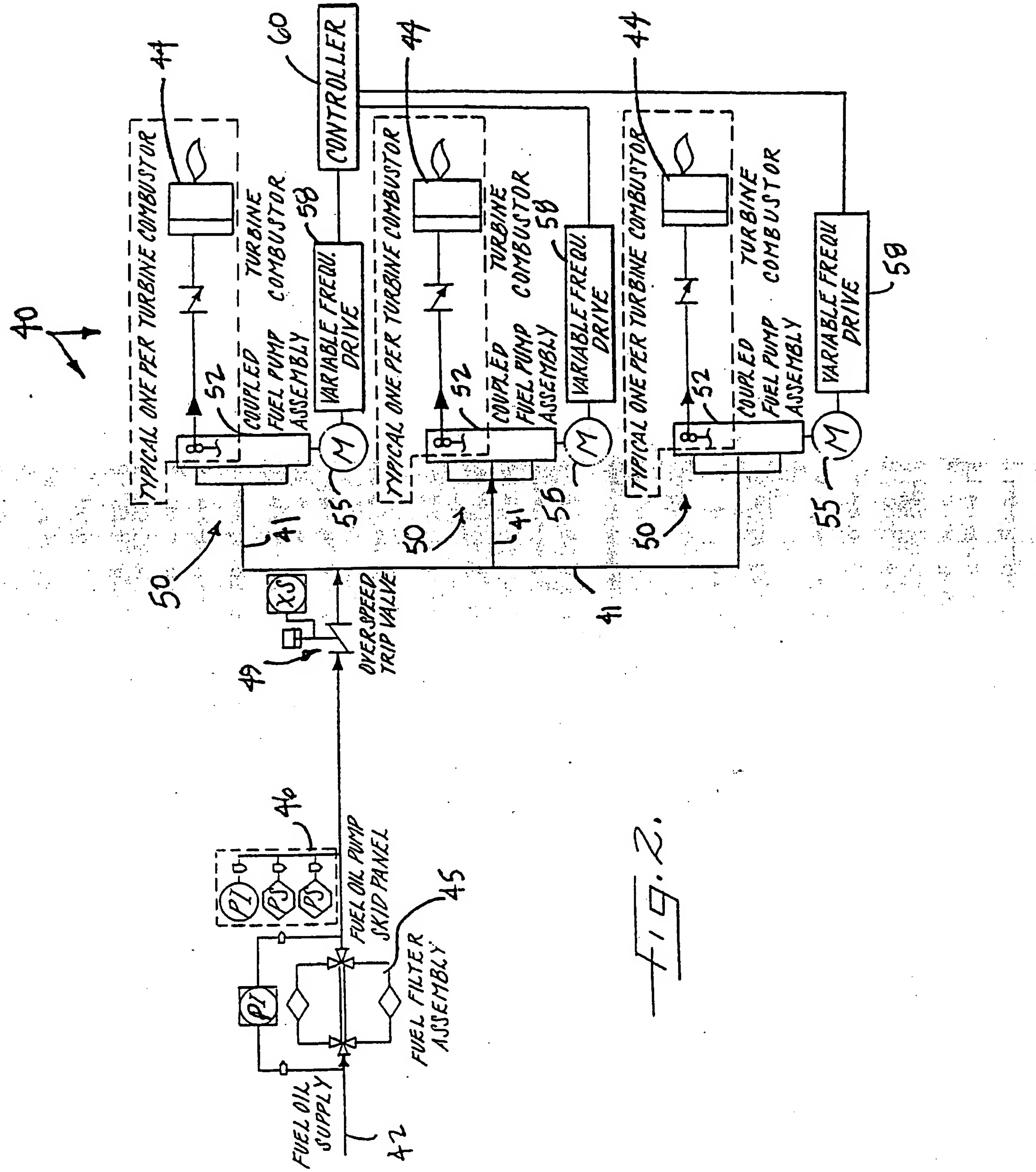
40
CONTROLLER
60
TYPICAL ONE PER TURBINE COMBUSTOR
TURBINE COMBUSTOR
44
52
COUPLED FUEL PUMP ASSEMBLY
VARIABLE FREQU. DRIVE
58
M
55
56
50
41
XS
OVERSPEED TRIP VALVE
49
PI
PS
46
FUEL OIL PUMP SKID PANEL
45
FUEL FILTER ASSEMBLY
FUEL OIL SUPPLY
42

Fig. 2.